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# Definition of specific comfort implications, indoor environmental and architectural quality.

**Evaluated by Danish single-family homeowners**

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## **Abstract**

*In the coming years, the European building sector faces a large challenge to reduce the energy consumption and CO<sub>2</sub> emission. Private homeowners need to participate in this process, but various barriers prevent them from conducting extensive energy renovations. Studies have, nonetheless, shown that improvements in indoor environment, comfort and architecture can motivate the Danish homeowners to complete energy renovations. In order to utilize these results and thereby reduce the energy consumption in the existing Danish building stock, this paper examines which aspects of indoor environment and comfort the homeowners find essential, and which level of architectural change they prefer. The presented results derive from a survey conducted January 2012 where 883 homeowners completed a questionnaire about energy renovation. The aspects found most crucial for good indoor environment and comfort are stable*

*and right temperature, good and plenty daylight, the ability to open windows and get fresh air, optimal lay-out and no draught. Preferably, the architecture should undergo some changes, but it is essential that the original style of the house is respected. The life-cycle situation is the key element to consider when motivating the homeowners since this can influence the effect of the motivation in both negative and positive direction.*

## **Keywords**

Energy renovation, homeowners, motivation survey, indoor environment, comfort, architecture.

## **1. Introduction**

The European Union has set targets for the size of the energy consumption and CO<sub>2</sub> emissions in respectively 2020 and 2050 [1,2] and is facing a huge task of reaching these goals in the coming years. The 2020 objectives are to reduce the energy consumption by 20%, reduce the greenhouse gas emissions by at least 20% compared to 1990 levels and have 20% of the energy consumption covered by renewable energy. By 2050 the European Unions goal is to reduce greenhouse gas emissions to 80-95% below 1990 levels [1,2]. The energy saving potential in the building sector is very high in both Denmark and in the rest of Europe, in the existing building stock in particularly [3,4,5]. Since the majority of the dwelling stock in Europe is privately owned (74 %) [3], the private homeowners need to be motivated to renovate their houses and do so with the additional benefit of achieving energy savings i.e. so called energy renovations.

*“The rate of building renovation needs to be increased, as the existing building stock represents the single biggest potential sector for energy savings. Moreover, buildings are crucial*

*to achieving the Union objective of reducing greenhouse gas emissions by 80-95 % by 2050 compared to 1990.”[2]*

An energy saving of 58 TJ is calculated to be possible if the building envelope of all existing Danish buildings erected between 1850 and 1998 are renovated to the level of building regulation 2008 for new buildings [4]. The biggest potential energy saving resulting from renovation of a single building typology, which is also economical sensible to renovate, is in Denmark found in the approximately 440,000 single-family houses erected in the 1960s and 1970s. Here a potential saving of 7.811 TJ is possible if the building envelopes are renovated to a level comparable to the buildings erected according to the building regulations from 2008 [4].

The single-family house is the preferred home of Danish citizens [6]. This is clearly underlined by the fact that in 2010 approximately half of the Danish population lived in these houses. Around 42% of the total Danish single-family housing stock (1,037,091 houses) were erected between 1960 and 1979 [7] where a genuine building boom took place and the same amount of houses as in the previous 100 years together were erected over a 20 year period [6]. The survey presented focuses on energy renovation of this particular building typology, because of the amount of typologically similar houses and the high energy saving potential found here, but also since these houses are ready for renovation in these and the coming years due to their age and it is economically sensible to integrate energy savings in connection to these renovations. If not included in the first coming renovations energy saving initiatives can be very expensive and many years will pass before ordinary maintenance again is needed and provides the opportunity to include the initiatives in a cost-effective manner. Furthermore does the standardization of the houses allow for renovation solutions to be applied to numerous houses with a minimum of alterations and thereby keep the price of the work lower than what is the case when a house

needs costume made solutions. Besides the evident potential energy savings many other none-energy benefits can be expected from an energy renovation. Among others are improved indoor environment and comfort often a “free” gain from energy renovation and today many of these houses lack this.

Despite the obvious reasons for energy renovation various barriers still prevent many both professional and homeowners from conducting these projects. The most significant barriers are related to economy (uncertainty about the size of savings and investment and lacking economic incentives) but also the homeowners’ lacking knowledge and interest in energy renovations and savings are challenges not to be neglected [3,8,9,10].

The data presented in this paper is from a questionnaire survey carried out in January 2012 where 4,000 Danish single-family house owners were invited to participate and 883 of them completed a questionnaire about energy refurbishment and renovation, assessment of the quality of their private house and their view on aspects related to energy consumption, architecture, comfort, indoor environment and investments for renovation. Two analysis [11,12] with different objectives have previously been conducted with some of the data from the questionnaire survey. Results from the two analyses are the background for the analysis presented in this paper, The first analysis [11] of the survey data had the objective of determining if, and if so, how the average Danish single-family homeowners can be motivated to conduct energy renovations on their private houses. The conclusion is that it is possible to motivate the homeowner to conduct energy renovations if it, besides energy savings, results in improvements in comfort, indoor environment and architecture.

For these results to be utilized to the full potential and motivate the homeowners to save energy by building renovation, it is crucial to define which aspects the homeowners relate to good comfort and indoor environment respectively and what level of change in the architecture the

homeowner prefers. The first objective of this paper is to determine which aspects of the three parameters the average homeowners value as the most important to ensure that future motivation strategy can include the most profitable information.

A Swedish survey published in 2013 investigates how the occupants' satisfaction of different aspects of the indoor environment contributes to the overall satisfaction and which problems affect the overall satisfaction [13]. The survey was conducted with questionnaires sent to occupants living in multi-family apartment buildings. The quality of the indoor air proved to have the largest influence on the overall satisfaction. Problems in the indoor environment quality were often related to dust, outdoor noise and too low temperature. However noise did not seem to affect the satisfaction much despite it being a problem often recognized by the occupants. Reduction of problems related to draught, dust and too low temperature are on the other hand important to ensure the overall satisfaction. At the same time it is though pointed out that the overall satisfaction is very individual and affected by personal characteristics such as age, gender, lifestyle and health, but also by the location, design and construction of the building [13]. From this survey it can be extracted that the occupants find the indoor air quality very important, but also that some problems affecting in the indoor environment quality (draught, dust and too low temperature) play a significant role to the overall satisfaction.

A Danish study investigates the influence of various factors on occupants' comfort on the basis of a questionnaire survey among both owners and tenants [14]. The indoor environmental parameters evaluated were; air, thermal, visual and sound quality and overall environmental. The four quality parameters were all assessed as equally important to the overall environment and the acceptable level of these parameters were similar. When compared pairwise approximately half of the respondents find the parameters equally important, however air quality and temperature are by many evaluated higher than lightning and acoustics. To feel comfortable the parameters

most often mentioned by the respondents were light (sun), temperature (warmth) and fresh/clean air (smell). The importance of the fresh air is underlined by the fact that 86% of the respondents agree that the possibility to open the windows is very important to them. The daylight conditions play a large role when the respondents were arranging their homes. It is the third most important factor in this process. "Creating a cosy atmosphere" and "Purpose of the room" are the first and second most important parameter whereas indoor environmental parameters such as noise, draught and thermal conditions are in the bottom of the list [14].

From these two surveys it is clear that indoor environment and comfort cover various parameters, which all have different importance to the occupants of the buildings and their general satisfaction. Many of the parameters can be calculated and measured very accurate. Nevertheless is the calculated satisfaction level not always the level preferred by the occupants since the preferences are very individual and also influenced by the building characteristics [13]. Therefore it is of importance to define the occupants' preferences as precise as possible despite these being subjective if the survey results [11] should be beneficial and exploited in the best possible manner.

A second analysis of the questionnaire data [12] investigates if there are some demographic groups which separate themselves from the average homeowner in terms of the replies given and if so where the differences are. It was found that there are clear differences among the questionnaire replies in terms of interest in renovation, willingness to renovate and motivation factors when the respondents were divided into groups based on eight different background variables [12]. The background variables in question are; gender, age, household composition, place of residence, time of ownership, education, occupation and income. The homeowners' position in the life cycle namely a combination of many of the background variables has proven to be the main parameter affecting the investigated aspects and no single variable can be said to

have the same large influence on the interest, willingness and or motivation [12]. The second objective of this paper is to define whether the respondents' characterizations of good comfort and indoor environment and the preferred level of architectural change differ from the average homeowners' (first objective) when the respondents are divided according to the eight background variables.

Jungsoo, de Dear, Cândido, et al. have gathered results from previous surveys of gender differences in the assessment of various aspects of indoor environment [15]. The majority of the listed surveys conclude that large differences are found between men and women and the way they experience the indoor environment. Women are generally less satisfied with all the examined factors. The differences are hence not a coincidence but clearly show that the genders are not alike and that they require different indoor environment to be satisfied [15].

In an experiment Pan, Lian and Lan investigated if females and males experience different sleeping comfort at various temperatures. They examined the sleeping comfort at three different temperatures both by questionnaires and by measuring of the test persons' blood flow and skin and finger temperature. The results showed that females prefer a higher temperature when sleeping than males and also that men in general have better sleep quality than women despite the temperature. The researchers believe this to be caused by physiological characteristics since the experiment furthermore showed differences between the genders finger and skin temperature and blood flow during the sleep [16]. This experiment first of all proves that there are differences in the temperature preferences of the genders but also that physiological differences can be causing these differences indicating that females and males in many cases will perceive indoor environment and comfort differently. General calculation tools for optimal indoor environmental conditions would therefore not suit both genders, but is more likely to provide conditions not perfect for either of them since the tool will probably calculate an average condition. To create the



perfect conditions it is again necessary to look at the individuals to whom the indoor environment should be satisfactory.

Another study conducted in India examines whether gender, age, economic group, tenure and ownership affect the thermal comfort and acceptance [17]. The occupants were followed for 33 days over a three months period and their experience of the thermal comfort was compared to actual measured thermal data for each day. The survey concludes that the economic situation of the occupants had the highest level of impact on thermal sensation, preference, acceptance and neutrality. For instance did the lowest economic group accept higher temperature than the highest economic group. Whereas age, gender and tenure had little influence on the thermal comfort however some. The ownership made a difference to the thermal acceptance. Here the owners showed a much higher acceptance level to high temperatures than the tenants did. The owners also performed more initiatives to control the thermal conditions in their homes than what was the case in the rented homes [17]. Again this shows that people are not alike and in the question of comfort and indoor environment many factors play a part in the definition of the perfect conditions. Each person has their own personal preferences which are affected by various demographic parameters.

Knowing how influential demographic parameters can be it is found natural and essential to investigate whether, and how, the demography of the respondents affects the conclusions on the average important parameters of indoor environment, comfort and architectural change. The differences caused by demographic parameters, if any, can potentially be used to generate an even larger motivation for the homeowners to conduct the renovation since the presented gains can be targeted a more specific group of homeowners and their specific requests. The results presented in this paper are therefore means to increase the number and level of private energy renovations and through this get closer to the stated energy and CO<sub>2</sub> emission saving objectives.

The results can be utilised by craftsmen, manufactures, governmental institutions and others who have an interest in generating more and deeper renovations of the single-family building stock. The results presented in this paper are seen as unprecedented and providing new knowledge and guidance to the field of energy renovation and the understanding of the relationships between homeowners and their houses and define plausible motivation factors for future energy renovations.

First, the choice of method and approach are shortly described. Second, the most valued aspects of comfort and indoor environment by the homeowners are presented, and third the proposals for different levels of architectural change in relation to energy renovations are evaluated. Following is a discussion about the results and how these can be used in the future to motivate homeowners and increase the number of private energy renovations, and finally a conclusion highlighting the key results is given.

## **2. Description of method used**

There are different methods to use for social research, and the main two are quantitative and qualitative methods which both contain various approaches [18]. The questionnaire survey was carried out by the use of the quantitative method since the objective was to generalise a large amount of homeowners and, therefore, a higher number of participating respondents was more important than fewer in-depth details [11]. The benefit from the quantitative method and a questionnaire, which was the approach of this survey, is moreover that the respondents can easily be spread across the country because no personal interaction is needed. The absence of personal contact may further be an advantage in situations where the respondent is asked about his knowledge and morale. In these situations there can be a risk that the respondent bases his

answers on what he thinks the interviewer wants to hear or what is most socially accepted instead of giving an honest answer [18].

Furthermore, more respondents can participate within the same timeframe, compared to for instance a qualitative interview survey with the same questions, since the questions are predesigned and unchangeable, and the process is very structured. Therefore, the data processing is relatively easy to conduct no matter the amount of respondents [11].

### *2.1 Design of questionnaire*

The questionnaire was designed solely for homeowners since they are the ones to be motivated, and so it was found natural to only ask them about their opinion towards the subject. The target group of the survey is Danish homeowners living in single-family houses erected between 1960 and 1979, and the questionnaires were evenly distributed across Denmark, with 1,000 sent out in the suburbs and cities of respectively Aalborg, Aarhus, Odense and Copenhagen [ill.1] [11].



ill.1: The four areas in which the questionnaire has been distributed with 1,000 examples in each region.

The questionnaire was divided into five themes to make it more visual and easy to go through for the homeowner. The five themes were as follows: 1) General information about the

respondents, 2) Energy consumption and renovation, 3) Architecture, 4) Comfort and indoor environment, and 5) Economy.

All respondents were randomly selected by the use of information from four district heating companies in respectively Aalborg, Aarhus, Odense and Copenhagen. The respondents' names were found via the webpage [www.ois.dk](http://www.ois.dk)<sup>1</sup> where each house was also checked for the year of construction [11]. An accompanying letter promised the homeowners anonymity and informed them about the survey objective, the authors and how to complete the questionnaire online (optional) [11].

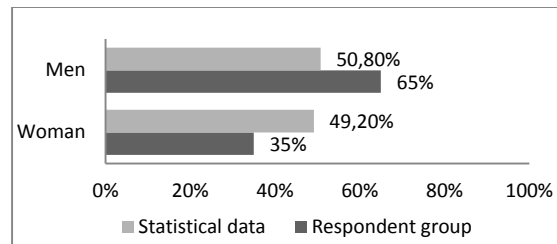
### **3. Survey representativeness**

#### *3.1 Respondents and statistical data*

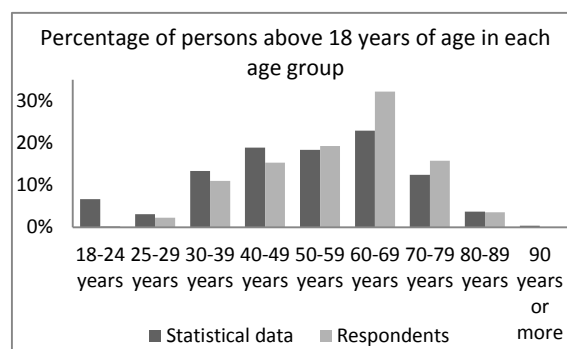
In the respondents group there are more men [ill.2] and homeowners older than 50 years [ill.3] than the case is in Denmark according to Statistics Denmark [11+19]. 59 % of the respondents have lived in their house for more than 20 years, which is also expected to differ from the statistics, but this cannot be verified by the available statistics [11]. This paper examines the data from the questionnaire survey by dividing the replies according to different demographic parameters. One of these parameters is gender, and any differences between the two genders will be made visible throughout the paper. The same will be the case with the age of the respondents and the time they have lived in their house [11].

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<sup>1</sup> [www.ois.dk](http://www.ois.dk) (Public information server) is a national database with data about buildings such as area, construction year and name(s) of owner(s) and is administrated by the Ministry of Housing, Urban and Rural Affairs.



ill.2: Distribution of gender in the respondents group compared to statistical data from Statistics Denmark of the 2012 distribution in Danish single-family houses erected between 1960 and 1979, for persons older than 18 years of age [9].



ill.3: Age distribution of the respondents compared to statistical data from Statistics Denmark of the 2012 age distribution of residents in Danish single-family houses erected between 1960 and 1979. [9] Data from 2012.

The geographic spread of the respondents is evenly divided since the questionnaire was sent to an equal amount of people in each region: Odense, 27 %; Copenhagen, 26 %; Aarhus, 25 %; and Aalborg, 23 % of the respondents. The statistic spread of single-family houses in each of the regions is a little different from the spread of the respondents. Copenhagen and surroundings have 32 % of all single-family houses in the four regions, Aarhus has 25 %, Aalborg has 24 %

and Odense has 19 % [7]. Despite this difference the results are seen as being valid for all four regions due to the equal spread of the respondents and are giving an average picture of the Danish homeowner which can be equally truthful in each of the regions.

### *3.2 Survey representativity, reply rate and uncertainty*

There are differences in the numbers from the respondent group compared to the statistical numbers. However, for the results in this paper where both the average and the differences between different groups are presented, it is found that the differences will not have a negative effect on the results nor make these untrustworthy. There are respondents in every category hence the survey provides an indication of which parameters affect the homeowners' evaluation of the comfort and indoor environment aspects and an indication of the preferred architectural changes. As a result, the survey can contribute with valuable information to the existing knowledge about how the number of private energy renovations in Denmark can be increased.

In some of the divisions, for example when the respondents are divided by their current occupation, some of the groups contain a low percentage of the respondents and, as such, the results from those divisions will not have the same credibility as other divisions. The groups containing less than 5 % of the respondents are as follows: 0-1 year of ownership (25 respondents), High school education (27 respondents), Enrolled in education (8 respondents), Unskilled worker (18 respondents), Semi-skilled worker (11 respondents), Receiver of unemployment benefit (20 respondents) and Other occupation (16 respondents). These results should, therefore, only be seen as indications of how these groups act and not as a conclusive result. In the following illustrations, these homeowner groups will easily be identified by being

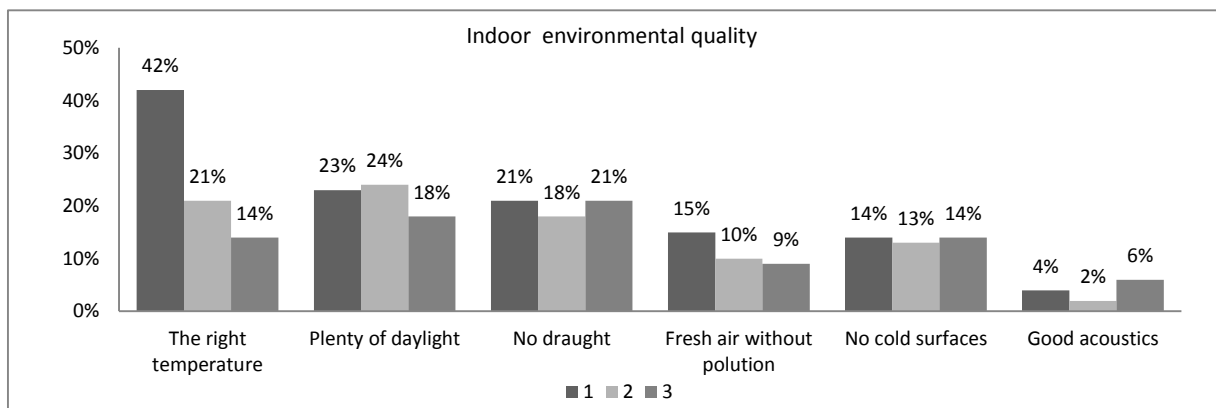
written in grey letters instead of black and in the text by being followed by (<5%) to illustrate that the group consists of less than 5 % of the respondents.

Of the 4,000 invited homeowners, 883 of them replied giving a reply rate of 22 %. With the typical used confidence level at 95 %, a population of 440,000 (the approximate number of Danish single-family houses erected between 1960 and 1979) and 883 responses give a confidence interval at 3.3 % with a random check calculator [209]. So the certainty of the survey is between 91.7 % and 98.3 % which is found reasonable for the results to be applicable and trustworthy [11].

#### **4. Which aspects of comfort and indoor environment are most important to the Danish homeowners?**

In this paragraph, results from the questionnaire survey will be presented to determine what the homeowners experience as being necessary to obtain indoor environmental quality and good comfort. First, a presentation of the average homeowners' preferences for indoor environmental quality and comfort implications will be given, followed by the groups of homeowners who separate themselves from the average results or from groups in the division. The demographic background variables by which the respondents are divided are as follows: gender, age, household composition, residence area, time of ownership, education and household income. The results are only presented if one or more of the groups (e.g. homeowners from Aarhus) in a division (e.g. Residence area) separate themselves significantly from the other groups/the average. If all groups in a division are close to the average, only the average result is presented.

The homeowners were asked to rate the six parameters below, according to their importance in ensuring indoor environmental quality. The most important was graded with 1, the second most important with 2 and the third most important with 3. The remaining parameters were not graded. The results clearly show that for the average homeowner 'The right temperature' is the most important characteristic in ensuring indoor environmental quality [ill.4]. As many as 42 % of the homeowners have chosen this parameter as their first priority, and 77 % have it among the top three. 'Plenty of daylight' and 'No draught' are respectively second and third most important with a total of 65 % and 60 % respectively of the homeowners having these in their top three list.

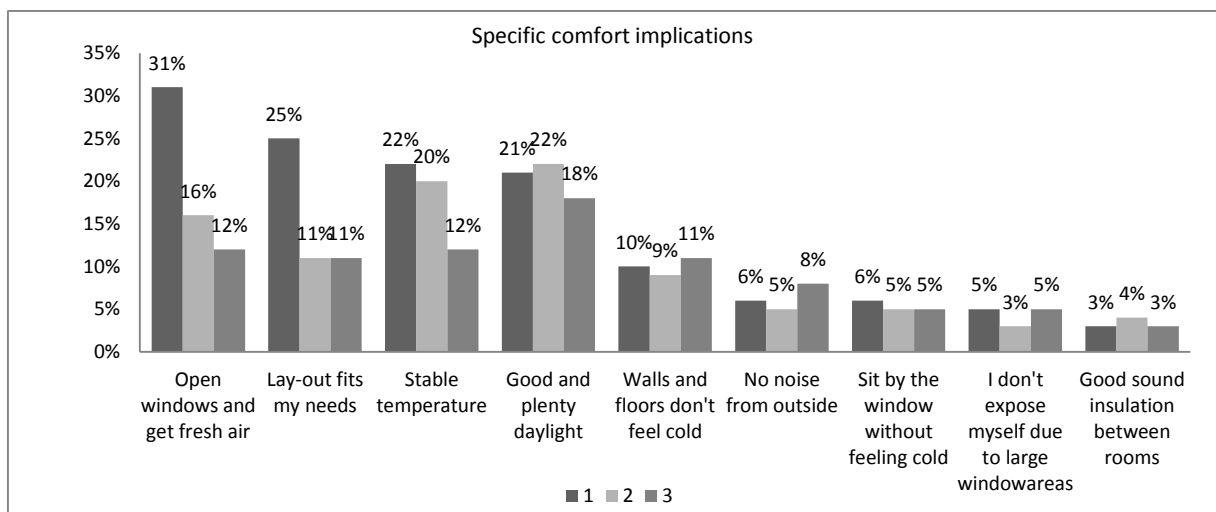


ill. 4 The six parameters of indoor environmental quality as evaluated by the respondents. 1 = the most important parameter to obtain indoor environmental quality, 2 = second most important and 3 = the third most important parameter.

In order to determine which of the comfort implications the homeowners find most crucial nine aspects were listed and the homeowners were asked to pick the three most important regarding good comfort. The homeowners could once again choose the three most important aspects and grade them with marks from 1–3. The implication which has been given most 1s is 'Open windows



and get fresh air' (31 %) [ill.5]. When looking at the aspect with the most votes in total, 'Good and plenty of daylight' is present in 61 % of the homeowners top three list. The four parameters: 'Open windows to get fresh air', 'Lay-out fits my needs', 'Stable temperature' and 'Good and plenty daylight' have received much more votes than the remaining five parameters and have all been chosen as first, second or third choice by more than 45 % of the homeowners.



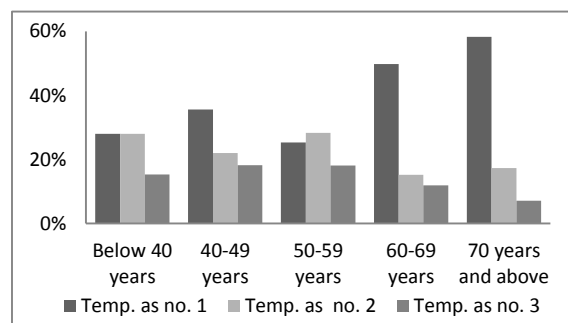
ill. 5 The importance of the nine comfort implications as evaluated by the respondents. 1 = most important aspect to obtain comfort, 2 = second most important and 3 = third most important aspect.

#### 4.1 Are there any differences among the homeowners according to their rating of the indoor environmental quality aspects?

When dividing the respondents into groups, the different aspects of indoor environment are evaluated differently from the average by some of the subgroups. The different evaluation between men and women is only present with the aspect 'The right temperature'. 47 % of the men have this as their main priority for good indoor environment while only 28 % of the women

have chosen this as the first criteria. The average number is 42 %. The remaining aspects are evaluated close to similar by the two genders.

The divisions according to age show that all age groups have 'The right temperature' as the most essential parameter for good indoor environment out of the six presented. There are, however, differences between how many percentages of homeowners who have this as their first priority. The older generation (above 60 years) have selected 'The right temperature' as their first priority much more than the younger generation [ill.6].



ill. 6 The homeowners divided by age and how they have rated The right temperature as a condition for indoor environmental quality.

The age also affects the importance of daylight. 14 % of the homeowners below 40 years of age have 'Plenty of daylight' as their first priority compared to between 23 % and 30 % of the respondents in all other age groups. For the other parameters, the age groups do not differ significantly from the average homeowners.

The age of the children in the household does result in some, however few, differences in the prioritisation of indoor environment parameters. The homeowners with children have almost the same view on 'The right temperature' as the first priority (32 -36 %) whereas the homeowners

with no children below 18 years have a much higher percentage (46 %). This result is the same as seen in illustration 6 where the older generation (those without children) put more importance in 'The right temperature' than the younger generation (those with children).

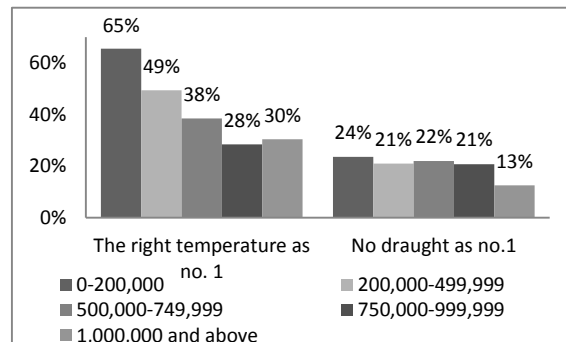
Whether the homeowners live in Jutland, Funen or Zealand has little effect on their prioritisation of the aspects. There are a higher percentage of homeowners from Odense and Copenhagen (43 % and 47 %) who have chosen 'The right temperature' as the main criteria than in Aalborg and Aarhus (both 38 %). The homeowners from Aalborg and Aarhus do, however, have higher percentages in 'The right temperature' as the second choice (26 % and 23 %) than those from Odense and Copenhagen (18 % and 17 %).

When the respondents are divided into groups according to the period of time they have lived in their houses, no significant differences are found between their prioritisation. All groups have 'The right temperature', 'Plenty of daylight' and 'No draught' in their top three, just as the average homeowner. The order for the three aspects changes though.

The educational background of the homeowners seems to have some influence on the evaluation of the six indoor environmental parameters. However, the six different educational background groups do all have the same three aspects at the top of their priority list and in the same order: 'The right temperature', 'Plenty of daylight' and 'No draught'. The differences between the groups become clearer when looking at the percentages from each group who have selected an aspect. An example is the way the respondents have prioritised 'Plenty of daylight'. 41 % of the homeowners with a high school education (<5%) have this as their main criteria for indoor environmental quality whereas only between 27 % and 18 % of the remaining groups have this

as the first priority. A total of 82 % of the respondents in the high school educational group (<5%) have it among their three most valued aspects whereas for instance just 59 % of the craftsmen group experience the same need for daylight.

The different income groups (yearly household income before tax) all agree on the prioritization of the six aspects except for the homeowners with a yearly income 750,000-999,999 DKK. They have 'Plenty of daylight' as the aspect which has received most votes (first, second and third ratings in total) instead of 'The right temperature'. Two tendencies are seen in this division when looking at the percentages of the top prioritised aspects: 1. The higher the income, the lower 'The right temperature' is prioritised and 2. The higher the income, the lower 'No draught' is prioritised [ill.7]. It should, on the other hand, be stated that the higher the income, the higher percentages have 'The right temperature' and 'No draught' as second and third priority respectively.

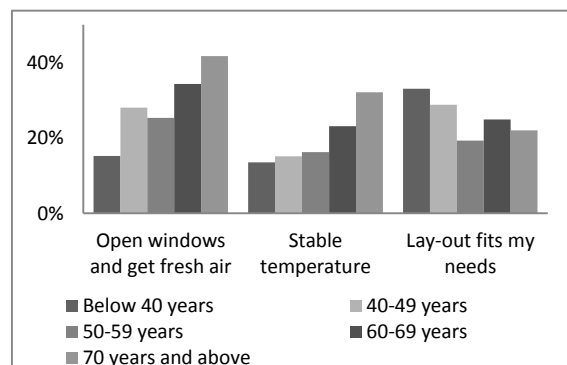


ill. 7 The different income groups (yearly household income in DKK before tax) and the amount of respondents in these who have chosen 'Temperature' and 'No draught' respectively as their first priority.

#### 4.2 Are there any differences among the homeowners according to their rating of the specific comfort implications?

The average picture of which comfort implications the homeowners find most important is very similar to the one seen when the respondents are divided in groups by their gender. Nonetheless, men have a tendency to prioritise 'Stable temperature' higher than women do. 25 % of the men have this as their first priority whereas it is 15 % for the women.

When divided by age, more differences occur. In three out of the four most important implications, the differences between age groups are significant. The tendency is that the older the homeowner is, the more important 'Open windows and get fresh air' and 'Stable temperature' are [ill.8]. For the importance of 'Lay-out fits my needs', the case is the opposite since the results here show that the younger the homeowner is, the more essential the lay-out is.



ill.8 The different age groups and their prioritisation of three of the comfort implications. Percentages of the groups who have given the aspects first priority.

The same tendency is seen in the division according to length of ownership where the importance of 'The lay-out fits my needs' decreases the longer the homeowner has lived in the

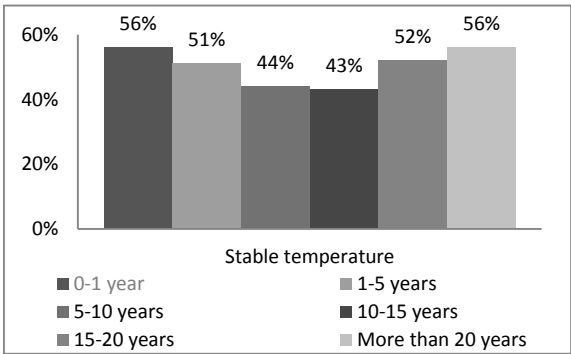
house. There is, however, an exception since only 36 % of the homeowners who have lived just one year in the house (<5%) have this implication in their top three list. After one year of ownership, this number increases to 56 % and then drops slowly to 43 % for the group who has lived for more than twenty years in the house. The percentage who has 'Open windows to get fresh air' among the three highest prioritized aspects are almost stable (57-64 %), but one group stands out. The group of respondents who has lived between one and five years in the house has a total percentage of only 42 %.

The homeowners who have no children under the age of 18 chose 'Open the windows and get fresh air' as their first priority for good comfort (34 %) more often than those who have children under the age of 18 (22-25 %). When adding both the first, second and third priority together, the groups end up with a result showing that the homeowners with children under the age of 9 years put the least importance into this aspect (52 %). Between 57 % and 62 % of the homeowners with children between 9 and 18 years and those with no children under the age of 18 years have this among their three highest prioritized implications for good comfort.

The homeowners with no children have, likewise, a higher total percentage (57 %) of those who request a 'Stable temperature' to obtain good comfort than those with children under 18 years (41-47 %).

Which implications are important to obtain good comfort are not the same for all homeowners in Denmark. There are variations in the way the homeowners rank them, but the total percentages for the three highest prioritised aspects are not significantly different for the four residential areas of the respondents.

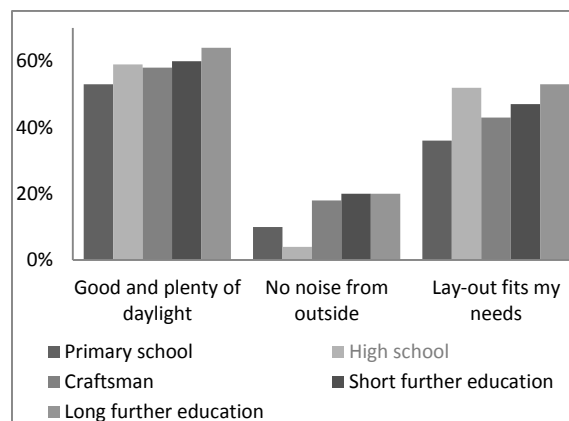
Depending on the length of time in which the homeowners have lived in their house, the nine aspects are evaluated differently. From the move-in year and until the fifteenth year, the importance of 'Stable temperature' drops, going from 56 % to 43 %, but after the homeowner has stayed for 15 years in the house, the importance increases again to 56 % [ill.9]. When the aspect 'Good and plenty of daylight' is evaluated, there are two main groups appearing: one group of those who have lived in their house up to ten years, and another group who has lived more than ten years in the same house. Between 66 % and 71 % of the homeowners in the first group have 'Good and plenty of daylight' in their top three priority list whereas the number for the other group is between 57 % and 58 %.



ill.9 The percentages of the respondents who have 'Stable temperature' in their top three priority list. The respondents are divided according to the length of time they have lived in their house.

The educational background of the homeowners can cause variations in the choice and order of the three most crucial aspects of good comfort. The percentages of each education group which have chosen 'Stable temperature' as either the most important or the third most important aspect vary a lot, but the total percentages of those who have this aspect among the three highest priorities aspects are within an insignificant span (50-58 %). A tendency has appeared when

viewing the total percentages of 'Good and plenty of daylight', 'No noise from outside' and/or 'Lay-out fits my needs' among the three top priorities. It seems that the longer education the homeowner has, the more important these three aspects become in order to achieve a good comfort [ill.10]. The high school group (<5%) does not fit right into the tendencies, but the other groups clearly underline the trend.



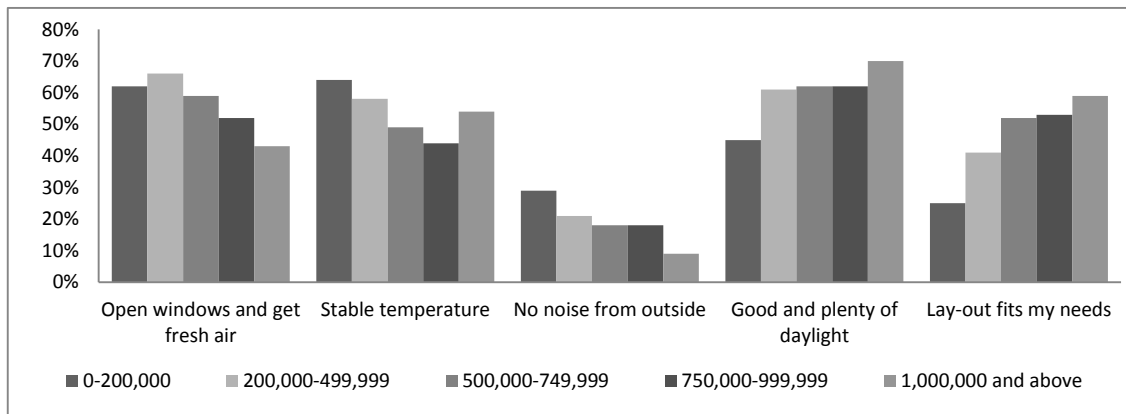
ill.10 The tendency of how the length of the respondents education influence the importance of three aspects in relation to good comfort.

For the aspect 'Open windows and get fresh air', the tendency is going in the opposite direction. Here, the homeowners with the shortest education (primary school) have a total percentage of 68 % with this aspect on the priority list. The number decreases evenly until it reaches 54 % in the group with the longest education (long further education).

For five out of the nine aspects, the income of the homeowners has some influence on the percentages which choose the different aspects as crucial for obtaining comfort. Two tendencies are clear when looking at the results: 1) the higher the income, the lower the importance of 'Open windows and get fresh air', 'Stable temperature' and 'No noise from the outside' is and 2) the



higher the income, the more significant the two aspects 'Good and plenty daylight' and 'Lay-out fits my needs' become [ill.11].



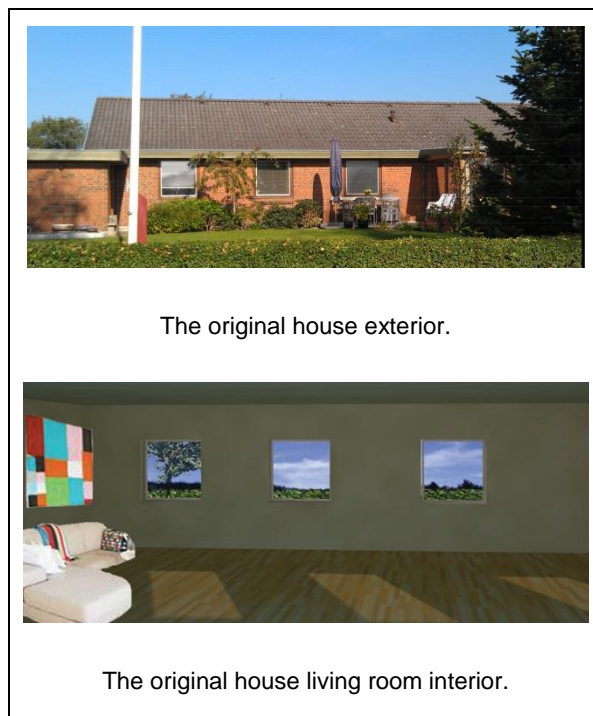
ill.11 Five comfort implications and their importance to ensure comfort as evaluated by five different income groups. The income is the yearly household income in DKK before tax.

## 5. Which architectural proposals are favoured by the Danish homeowners?

In this paragraph, the data from the questionnaire survey are analysis presented to define the homeowners' architectural taste and determine their preferred level of change; are they prepared to change the architectural style of their house in relation to an energy renovation, if they prefer to keep the original appearance or if there is a medium level where they request some changes but still want the original style to be visual. The same divisions and terms for presenting results are applied as for the previous paragraph.

Three cases of architectural changes due to three different renovation levels are evaluated by the homeowners. The homeowners were presented with the same pictures as seen below of the house before the renovation [ill.12] and proposals to how the expression can change in the three

different renovation cases. Case 1: replacement of windows [ill.13-15], Case 2: exterior envelope insulation [ill.17] and Case 3: extensive renovation where the roof is likewise changed [ill.19-21]. The proposals were purely evaluated on the basis of the architecture with no energy savings, prices etc. being mentioned.



ill.12 The original house before renovation. A traditional Danish single-family house from the 1960s and 70s.

### 5.1 Case 1: Replacement of windows

In case 1, the old windows are replaced by new and larger windows.



Proposal A exterior.



Proposal A living room interior.

ill.13 Case 1: Replacement of windows. Proposal A.



Proposal B exterior.



Proposal B living room interior.

ill.14 Case 1: Replacement of windows. Proposal B.



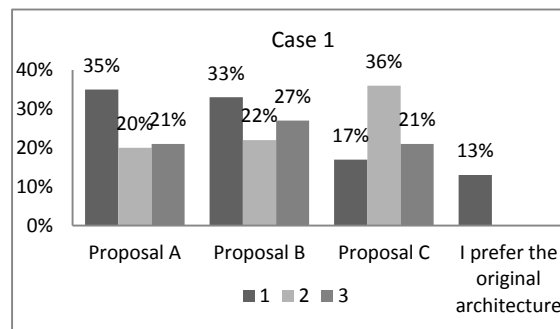
Proposal C exterior.



Proposal C living room interior.

ill.15 Case 1: Replacement of windows. Proposal C.

The average homeowners have evaluated proposals A and B almost identically as their architectural first priority for the replacement of the windows [ill.16]. Only approximately half as many have proposal C as first choice, and 13 % of the homeowners prefer the architecture of the original house over the proposals.



ill. 16 The average evaluation of the architectural expression in the three proposals for window change.

The main arguments for choosing proposal A are related to more daylight, view, connection to nature/garden, modern architecture and harmony/symmetry in the façade. The reasons for choosing proposal B are in many cases related to more daylight, flexibility in lay-out, a little modern but not too much. The reasons for why proposal C is not preferred are given by the majority of the statements as old look, industrial, difficult to furnish, inharmonious and split façade, and less daylight.

## 5.2 Case 2: Exterior insulation and finish

In case 2, the façade is reinsulated and provided with a new finish. The new windows from proposal A in case 1 are included.



Proposal A : White plaster facade.



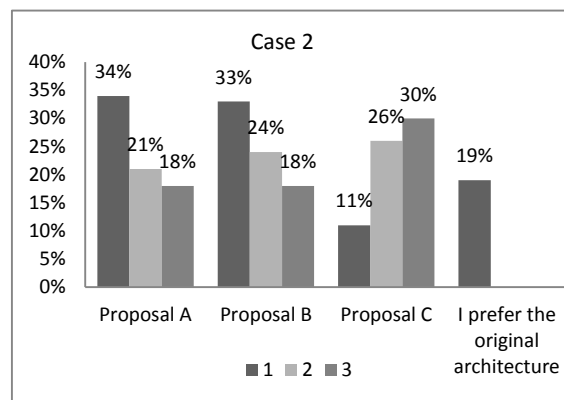
Proposal B : New brick facade.



Proposal C : Dark grey plaster facade.

ill.17 Case 2: Exterior insulation of the building envelope. Proposals A, B, C. Proposal A in case 1 is used to illustrate the window change included.

In case 2, two of the proposals once again have the same evaluation more or less. The proposal with the white plaster façade and the new brick façade are liked the most by the average homeowner [ill.18]. Almost one-fifth of the homeowners prefer the original façade, and only 11 % favour the new dark grey plaster façade.



ill. 18 The average evaluation of the architectural expression in three proposals for exterior insulation of the building envelope.

As in case 1, the respondents have argued for the preferred proposal and against the least favoured. The choice of proposal A is underlined by words such as modern, simple, pure style, contrast and light (both in terms of colour and appearance). For proposal B with the brick façade, the reasons are different. Here, the focus is very much on quality and durability of bricks, maintenance-free, a contemporary look and a general preference for bricks versus plaster. “*Bricks are maintenance-free and will always appear good-looking*” (Edit. translated). Proposal C is found too dark and gloomy, boring and heavy looking by most of the respondents.

### 5.3 Case 3: Extensive renovation

Case 3 is the extensive renovation where the roof construction is included in the work and so the proposals separate themselves very much from each other. Proposal A from cases 1 and 2 illustrate the replacement of windows and the exterior finish in all three proposals in case 3.



Proposal A exterior.



Proposal A living room interior.

ill. 19 Case 3: Extensive renovation. Proposal A. The proposals A from cases 1 and 2 are used to illustrate the new windows and envelope insulation.





Proposal B exterior.



Proposal B living room interior.

ill. 20 Case 3: Extensive renovation. Proposal B. The proposals A from cases 1 and 2 are used to illustrate new windows and envelope insulation.

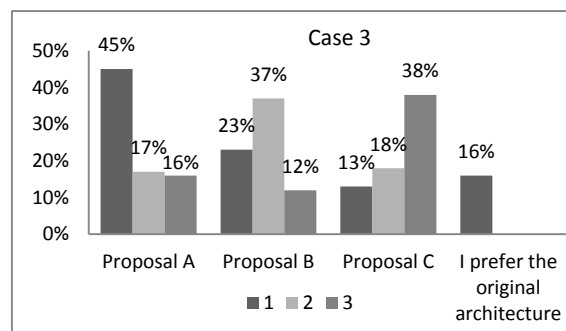


Proposal C exterior.



ill. 21 Case 3: Extensive renovation. Proposal C. The proposals A from the cases 1 and 2 are used to illustrate new windows and envelope insulation.

In case 3 where the house has had an extensive renovation with the roof construction also being part of the work, there is a clear difference found between the evaluations of the three proposals. With the pitch of the roof preserved as the original and the attic space included, proposal A is favoured by as many as 45 % of the homeowners [ill.22]. Proposal B, with an one-sided pitch and an increased room height, is the favourite for 23 % whereas proposal C with a flat roof and the original room height, and the original house are the first choice of respectively 13 % and 16 % of the homeowners.

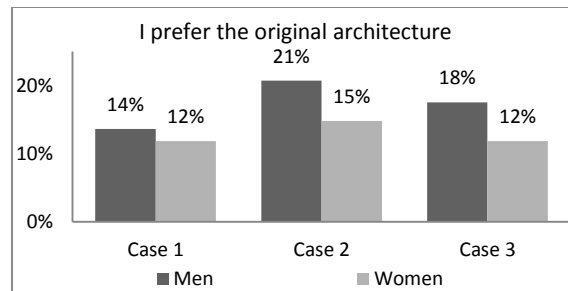


ill. 22 The average evaluation of the architectural expression in three proposals for an extensive renovation of a traditional single-family house.

The homeowners have commented on why they like or dislike the different proposals, and the reasons for preferring proposal A are, in many cases, related to the high amount of daylight from the skylights, the room height/sense of space and the fact that the house still has a reference to the original house because of the maintained roof pitch. *"You retain the "history" of the house but get skylights which is really good."* (Edit. translated) and *"High ceiling with skylights gives superb visibility. Probably fits in okay in the single-family house neighbourhood."* (Edit. translated) are both statements from the respondents, covering the general feel for proposal A. Proposal C appears as too modern and too changed for the homeowners. Many of the respondents have a general dislike towards flat roofs and many say that the house will not at all fit in with the surrounding houses.

#### 5.4 Are there any differences among the homeowners' view on the architectural proposals?

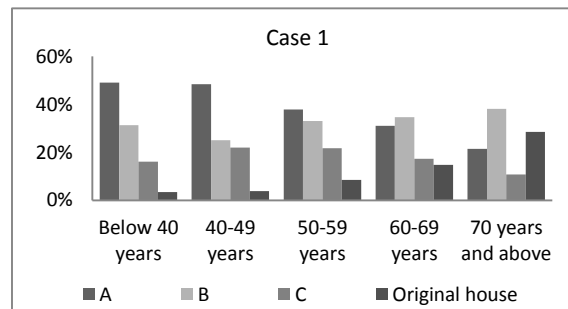
The proposals which the male and female respondents prefer are almost similar to the average responses. There is, however, an overweight of women who prefer proposal C in case 1 (14 % of the men versus 23 % of the women) and proposal A in case 3 (41 % of the men versus 53 % of the women). Furthermore, the tendency is that the men favour the original architecture more than women [ill.23].



ill.23 The respondents divided by gender and in relation to their preference of the original architecture in the three cases.

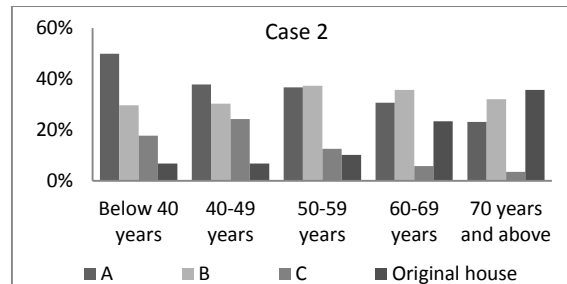
The age of the homeowners has a large effect on which architectural proposals they prefer. A clear tendency is found in all three cases: the older the homeowners are, the more they prefer the original architecture of the house. In cases 2 and 3, the homeowners above 70 years of age even prefer the original architecture over the proposals of changed architecture.

In case 1 (change of windows), the homeowners below 60 years favour proposal A, and after the age of 60 years they like proposal B the most [ill.24].



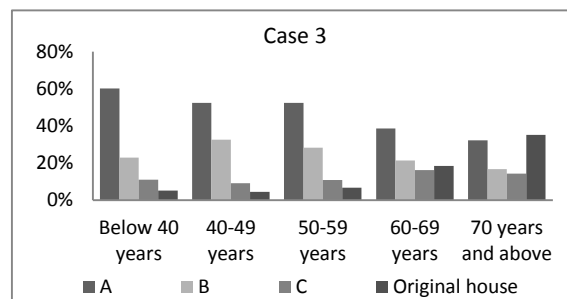
ill.24 The evaluation of the proposal in case 1 divided by the five age groups.

In case 2, the homeowners can be divided in three groups. The first group under the age of 50 years favours proposal A. The next group from 50–70 years prefers proposal B whereas the homeowners above 70 years of age prefer the original house [ill.25].



ill.25 The evaluation of the proposal in case 2 by the five age groups.

In the third case with the extensive renovation, all homeowners below the age of 70 years are most pleased with the architecture of proposal A. After the age of 70, the homeowners prefer the original house as is the case in case 2 [ill.26].

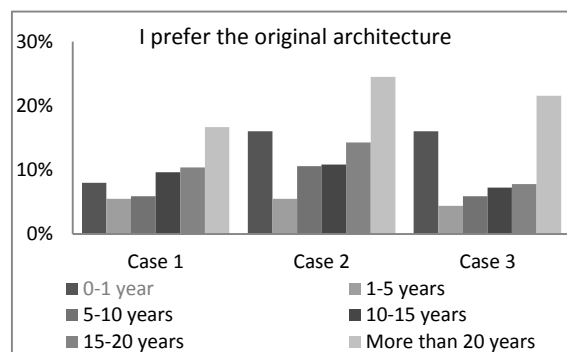


ill.26 The evaluation of the proposal in case 3 by the five age groups.

When the respondents are divided by the length of time they have lived in the house, the differences in the preferred architecture in the three cases are not big. In case 1, the homeowners

who have lived in their house for less than 20 years favour proposal A, and those who have lived there for more than 20 years are fonder of proposal B.

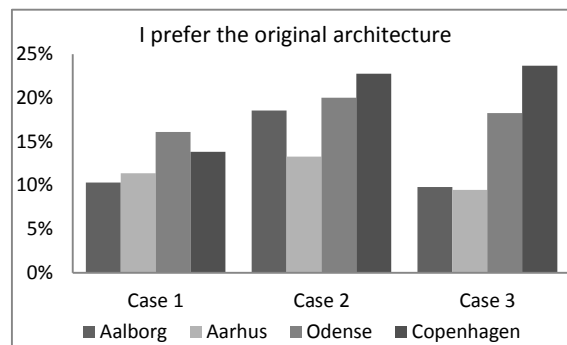
Despite this, there is a tendency which to some degree reflects the tendencies of the age division. The longer the homeowner has stayed in his house, the more he appreciates the original architecture [ill.27]. The exception is the homeowners who have lived in the house for less than one year (<5%). Especially in cases 2 and 3, they like the original architecture more than those who have lived in the house for up to 20 years.



ill.27 The respondents divided by the length of time they have lived in their house and how this affects their preferences for the original architecture.

A similar tendency is found in the division according to the age of the children in the household. All homeowners agree that proposal A in all three cases is the most suitable architectural solution except in cases 2 and 3 where the homeowners with no children under the age of 18 years separate themselves from those who have children since they prefer proposal B in both cases. The homeowners with no children under the age of 18 years in the household are much fonder of the original architecture of the house than those who have children in the house, which reflects the preferences of the homeowners when divided by age [ill.24-26]. Those without children in the house will, in many cases presumably, be the same as the respondents in the older generation.

The residence area of the homeowners has shown to have an effect on the architectural preferences. The preferred proposal in case 1 is for Aalborg, Aarhus and Odense proposal A; for Copenhagen the favourite is proposal B. Proposal A is the preferred architecture in case 2 for Aarhus and Odense whereas Aalborg and Copenhagen prefer proposal B. In case 3, all agree on proposal A as the best solution. None of the groups have the original house as a favourite in any of the cases, but the results show that the homeowners from Odense and Copenhagen like the original architecture more than those from Aalborg and Aarhus [ill.28].

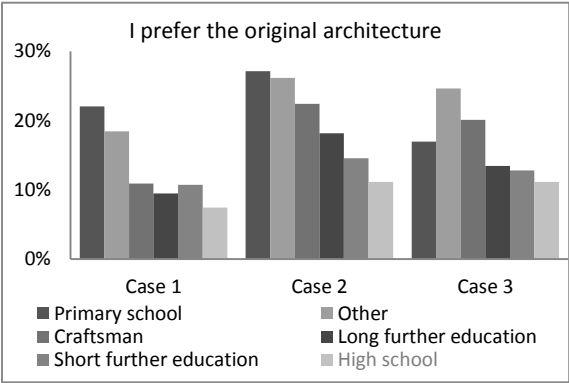


ill.28 The amount of respondents from each city who prefers the original architecture in the three cases.

The occupation of the homeowners has also some effect on the architectural preferences. All homeowners chose proposal A in case 1 as the best, except the pensioners who favour proposal B and those enrolled in education (<5%) who have two favourites: proposals A and C. In case 2, the preferred proposal is A, once again with the exception of the pensioners who are fonder of the original house and also the salaried workers who also have proposal B as a favourite. Everybody agrees on proposal A as being the preferred result in case 3. The pensioners represent the only group who prefers the original house more than the average homeowner, and it is clear

that this group reflects the older generation [ill.24-26] and their preferences for the original architecture.

Not much difference is found when the respondents divided by educational background are compared to the average respondents. Only when looking at the percentages that prefer the original architecture over the proposals, do the differences appear [ill.29]. The homeowners with primary school, craftsman or other education as their last finished education favour the original house more than average homeowner.

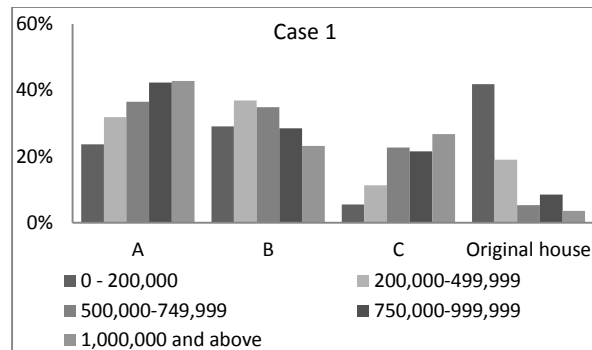


ill.29 The differences among the educational groups who prefer the original architecture of the house.

The income of the homeowners has significant influence on their evaluation of the proposals. A clear tendency is found among the income groups. The lower the income is, the more the homeowner favours the original house over the proposals [ill.30-32].

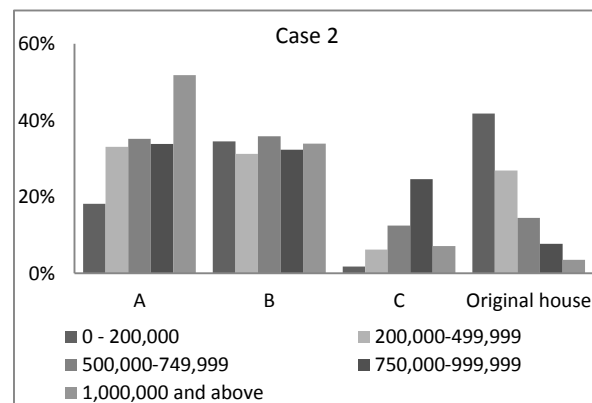
In the first case, proposal A is preferred by the three groups with the highest income. Those who have an yearly household income of 200,000-499,999 DKK are fondest of proposal B whereas the lowest income group favours the original house over the proposals [ill.30].





ill.30 The respondents divided by their yearly household income in DKK before tax and how this affects which of the proposals the homeowners prefer.

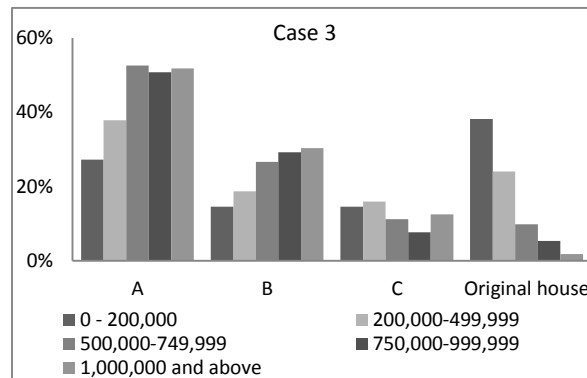
In case 2, the highest and lowest income groups clearly stand out from the other groups [ill.31]. The lowest income group again favours the original architecture, and a significantly high percentage of the highest income group prefers proposal A.



ill.31 The proposals of case 2 as evaluated by the five different income groups. The income is in DKK before tax.

In the case of the extensive renovations, proposal A is preferred by all homeowners with a yearly income of more than 200,000 DKK [ill.32]. Of the three highest income groups more than

50 % prefer proposal A. The only group who has another preference is the lowest income group who favours the original house.



ill.32 Case 3 proposals evaluated by the respondents divided by their yearly household income before tax.

## 6. Discussion

As in the referred surveys [13,14] the homeowners in this survey don't find all aspects of indoor environment, comfort and architecture equally important, but have some aspects which are crucial to obtain quality and others which are of less importance. Which aspects of the indoor environment and comfort that are found most important by the occupants will depend on the reply options in the surveys and therefore the results cannot be directly compared to this survey. If the exact same reply options are not presented to the respondents, it cannot be expected that results will be the same, not even if the respondents are allowed to write their own answers. In most cases the respondents will mark one of the predefined replies instead of writing his own formulation although other replies might be more descriptive for him and his situation [21]. In the surveys about demographic influence [15,16,17] the demographic parameters clearly affect the results and the same is the case in the presented questionnaire survey. Despite the three surveys

being conducted far from Denmark the impact of the demography is just as clear. The eight demographic variables used for this survey have different levels of influence, but all have some effect on the presented data when the respondents are divided by these just as in the two referred surveys.

The three aspects which the average homeowners find essential for indoor environmental quality and the four most important comfort implications [ill.4+5], have proven to be the same for the majority of the homeowners when divided into groups defined by the eight demographic variables. Three groups have changed the aspect 'Lay-out fits my needs' with 'Walls and floors don't feel cold' when it comes to obtaining good comfort. These groups are those who have lived up to one year in the house (<5%), those who have another educational background than mentioned in the questionnaire and those with a yearly income below 200,000 DKK before tax.

Despite the predominating similarity in prioritisation, there are differences between the groups in relation to how important one aspect is to them and if it is the first, second or third priority. The importance of the aspects clearly changes depending on where in the life-cycle the homeowners are. For example, the tendency is that the older the homeowner is, the more important the ability to 'Open windows and get fresh air' and that 'The temperature is stable' are to the comfort [ill.6]. For the optimal lay-out, the case is the opposite since the results here show that the younger the homeowners are, the more essential it is that the lay-out fits their needs.

Some of the background variables such as education, gender, length of time lived in the house and residential area can be said to be least cross-related to other variables and the differences found here are, therefore, especially beneficial. For instance, do illustration 10 shows that the longer the education the homeowner has, the more valuable daylight, no noise from the outside and a lay-out which fits the needs of the homeowner are. The results can be used purely with the educational background in mind and are not highly cross-related to other variables. The aspects

'age', 'age of children', 'years lived in the house', 'occupation' and 'income' will, on the other hand, in many cases be related and overlapping, and so the results from these divisions are more uncertain if conflicting. However, the results do show similarities which are underlined by the different division. An example is that the right temperature gets more important as the age increases [ill.6], and the lower the income, the more important is the right temperature in order to obtain indoor environmental quality [ill.7]. The oldest group of homeowners will, in many cases, also be represented in the group with the lowest income, and hence the results emphasise the tendency. It can, therefore, be said that none of the variables have more impact on the aspects than others, but the combination of the variables, more specifically the life-cycle situation of the homeowner, can tell by which aspects the homeowner presumably can be motivated the most.

The general importance of a fitting lay-out for good comfort [ill.5] can be linked with and underlined by the conclusions of the previous study [11] where improvements in the lay-out opportunities are seen as good motivation for homeowners to perform energy renovations. This aspect can consequently be a part of improvements of comfort, but also a beneficial part of improvements in architecture. The same is the case for daylight and temperature which are highly valued aspects of indoor environmental quality and comfort implications [ill.4+5]. The fact that one aspect is present in two of the motivational parameters makes it that much more effective and profitable for the forthcoming work of motivating homeowners.

The proposed architectural changes for the three renovation cases have, in most cases, been evaluated similarly by all homeowner groups, but there are differences which can be beneficial in the future process of motivating the homeowners. The fact that most homeowners find plenty and good daylight important to obtain both good comfort and indoor environment and that the architectural proposals with a high level of daylight are the preferred [ill.16+22] shows that daylight is an aspect which can be advantageous in more variations. An energy renovation which ensures

more daylight can be motivational on several fronts because it improves both comfort, the indoor environment and the architecture and, therefore, could have impact on the majority of the homeowners.

An extensive energy renovation can, if wanted, entail big changes in the architectural appearance of a house. 35 % and 34 % respectively of the homeowners have indicated in case 1 and 2 that they are ready for some drastic changes [ill.16+19] whereas in both cases 33 % have chosen the most traditional solution (apart from the original) as the preferred. In the case of the extensive renovation (case 3), this preference changes and the most radical modification [proposal C, ill.21] is the least favoured of the proposals [ill.28]. The comments on why this solution is not preferred clearly show that the house has changed too much. From these results, it becomes clear that when looking at the average homeowner, some changes and modern initiatives are appreciated, but it is very important that the original house is still present after the renovation and that the house will still fit in with the houses in the surrounding neighbourhood. The motivation by improved architectural appearance should consequently be done carefully and with respect to the original house.

For some of the homeowners, especially the older generation, the original architecture of the house is the preferred result. Consequently the ability to perform an extensive renovation with the appearance of a 1960s house will be a crucial aspect if these homeowners are to be motivated. Those who prefer the original house in one or more cases are the following: homeowners above 70 years of age [ill.26+26], pensioners, and those who have a yearly household income of less than 200,000 DKK before tax [ill.30-32]. These three groups will, in many cases, cover the same persons, and this is also clear when their evaluation of the comfort and indoor environmental aspects are examined. All three groups have rated the right/stable temperature, ability to open windows and get fresh air and no noise from outside higher than average, and therefore these

three parameters should be the primary motivation for an energy renovation of their houses instead and not the architecture.

The divisions of the homeowners according to background variables revealed tendencies of who is most pleased with the original architecture and who is more content with the modern proposals. The eight background variables all affect the preferences for the original house. Five of the variables (age, household composition, time lived in the house, occupation and income) are somewhat interlinked and underline a clear tendency: the longer the homeowner is in the life-cycle, the more he favours the original architecture. The tendencies found are as follows: the older the homeowner, the more favoured the original house is [ill.24-26]; the older the children are, the more favoured the original house is; the longer time lived in the house, the more favoured the original house is [ill.27]; the lower income, the more favoured the original house is [ill.30-32]; and pensioners favour the original house more than any other. The tendency of who prefers a new/modern architecture is the exact opposite: the earlier in the life-cycle the homeowners are, the more they are ready for and appreciate changes. There is, therefore, not one single variable which standing-alone can be said to determine if the homeowner is ready for a big architectural change or if the design changes should be kept to a minimum. The life-cycle situation, namely a combination of many background variables, is the best guidance for how the homeowners can be influenced the most by the improvements.

## **7. Conclusion**

Four comfort implications have proven to be the most crucial for the homeowners: 'Open windows and get fresh air', 'Lay-out fits my needs', 'Stable temperature' and 'Good and plenty daylight'. For obtaining indoor environmental quality, the three aspects 'The right temperature',

'Plenty of daylight' and 'No draught' are necessary for the average homeowner. Improvements of these aspects caused by energy renovations are expected to be the most constructive motivation in the future when utilising enhancements of comfort and indoor environment as motivation. Two of the aspects (Daylight and Temperature) are highly valued in both comfort and indoor environmental quality, which make them even more crucial and effective.

Some modernization of the architectural appearance is preferred by the homeowners, but the original house design must still be present and visual after a renovation. Only a limited number of homeowners are ready for a major architectural modification of their house.

The average results can be beneficial for the full target group and cover all homeowners. The homeowners can, however advantageously, on a general level be divided into two main target groups: the younger and the older generation. For these two groups, the motivation strategy ought to be addressed very differently so as to be more profitably than the average motivation. The younger generation can be motivated more than average by improvements in lay-out opportunities, by increase in daylight level and by new architectural solutions. For the older generation, the most influential improvements are expected to be a stable temperature, a good sound insulated house and the ability to open windows and get fresh air. This generation will prefer the architectural changes to be as minimal as at all possible and actually favour the original house over the suggested changes.

Both in terms of the comfort implications and the indoor environmental quality and in relation to the potential changes in the architectural appearance, the impact of the life-cycle situation of the homeowners is significant. An understanding of this and the affect it has on the different motivation factors and the valuation of the aspects herein can and should therefore be a necessary part of the future motivation strategy in order to benefit the most from the work by differentiate and taking into consideration the actual target group.

## **8. Acknowledgements**

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